The consequence is that MES users in motion, say those in vehicles driving rapidly past a particular microwave oven, might experience little or no interference because only a limited number of pulses would be received, and not all of the interfering pulses would be of the same high power. On the other hand, a stationary MES being operated a microwave oven might receive unacceptable interference throughout an entire connection. In such cases, the operational techniques discussed below would eliminate the interference.

Another indication, supporting the conclusion that emissions from microwave ovens are concentrated around 2450 MHz, the center of the ISM band, is shown in Figure 7. This figure plots the spectral distribution of a typical microwave oven.

## 2. Operational Techniques to Avoid Residual Interference

Although instances of interference from microwave ovens, or other ISM devices, will be rare and localized, operational techniques are available to MSS system operators to provide interference-free channels to users at all locations at all times.

As discussed in the section on possible interference from ITFS channel A-1, the Globalstar MSS system is designed to automatically reassign the user to a channel frequency with less interference when required.
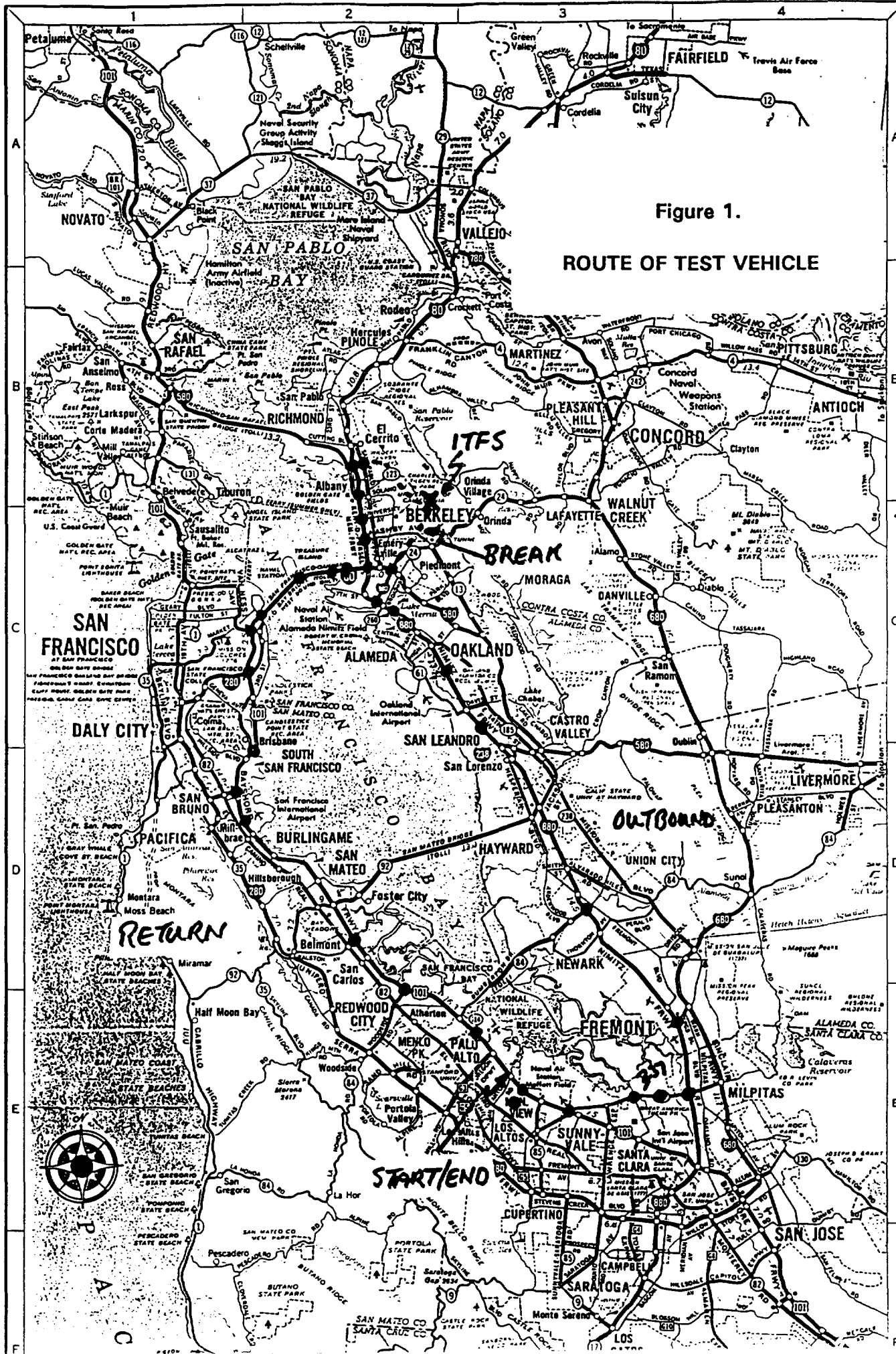
Figure 1.

ROUTE OF TEST VEHICLE

Figure 2.

ISM Band & ITFS Channels A1 & B1
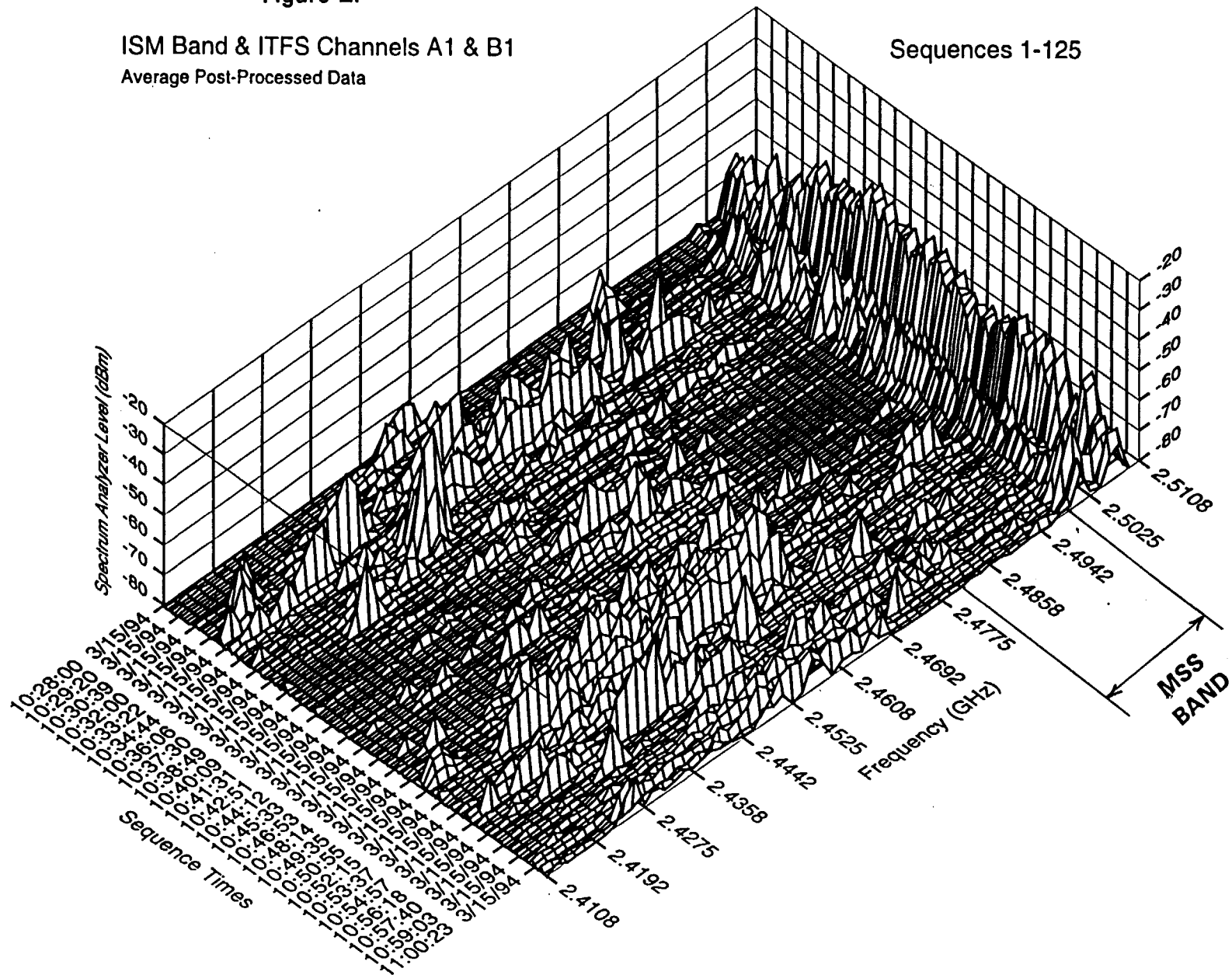Average Post-Processed Data

Sequences 1-125

F0315A.DG Avg    1

**Figure 3.**

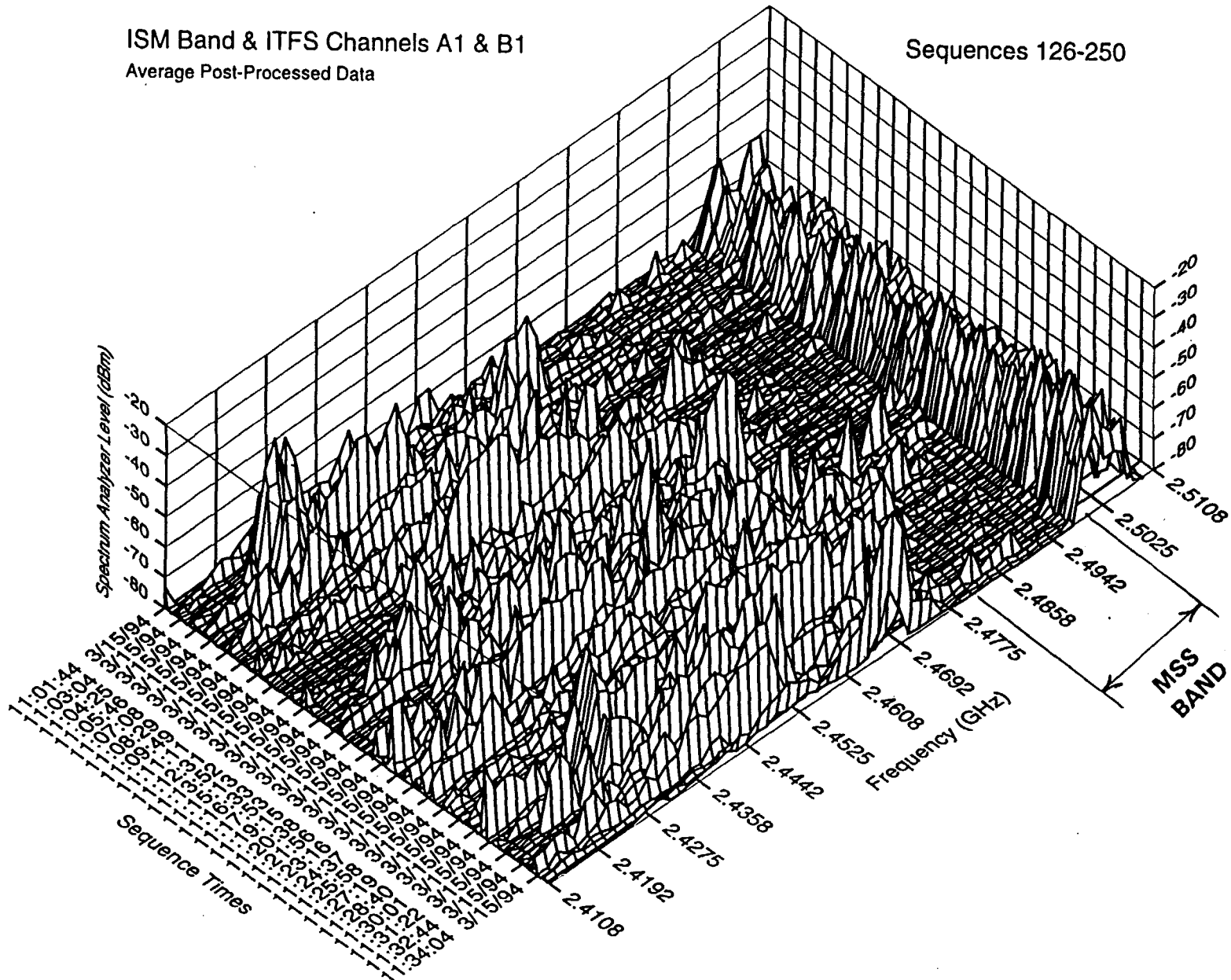ISM Band & ITFS Channels A1 & B1
Average Post-Processed Data

Sequences 126-250



F0315A.DG Avg    2

**Figure 4.**

ISM Band & ITFS Channels A1 & B1
Average Post-Processed Data

Sequences 251-370

Spectrum Analyzer Level (dBm)

Frequency (GHz)

MSS BAND

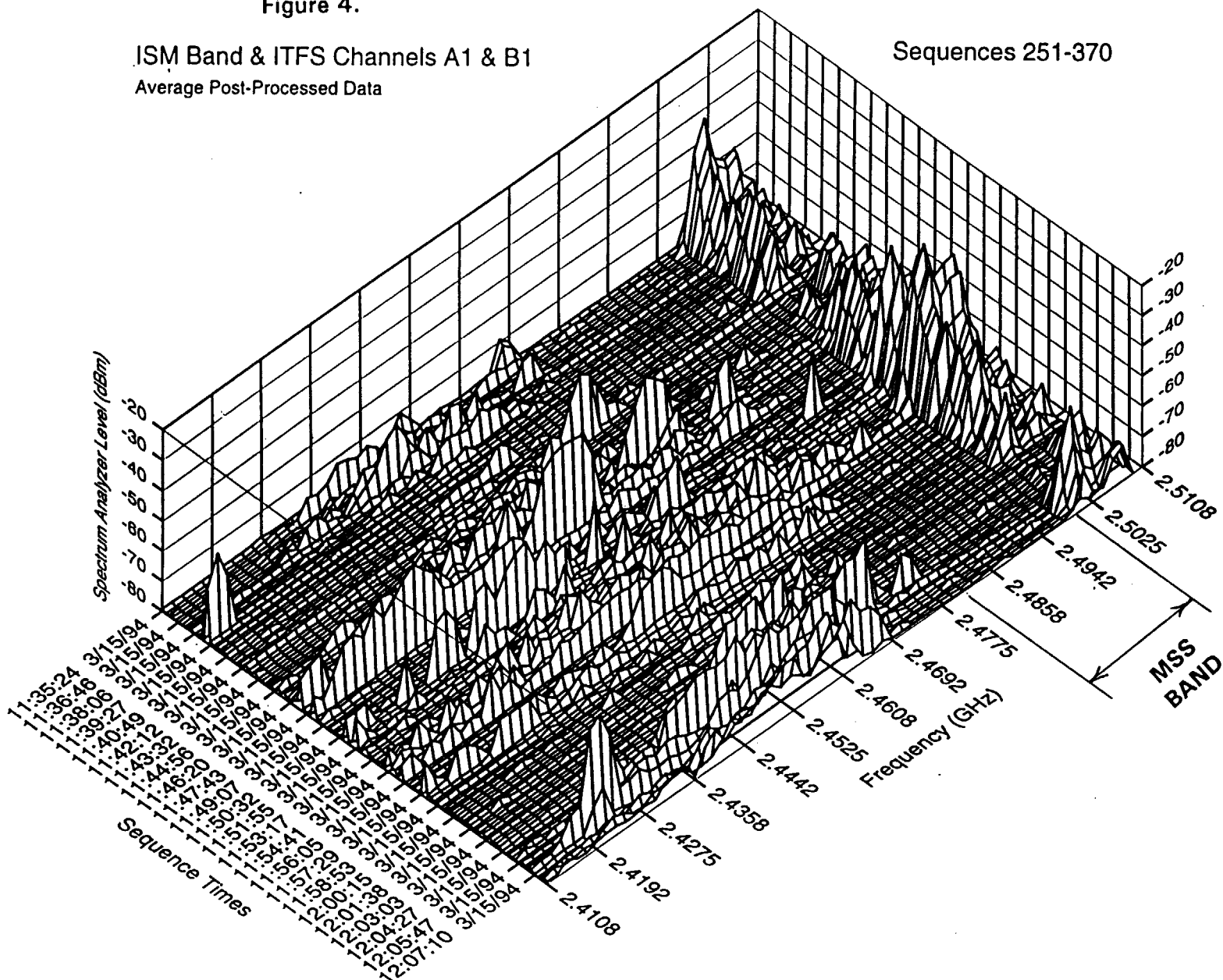Sequence Times

F0315A.DG Avg    3

Figure 5.

ISM Band & ITFS Channels A1 & B1
Average Post-Processed Data

Return Trip Set
Sequences 1-125

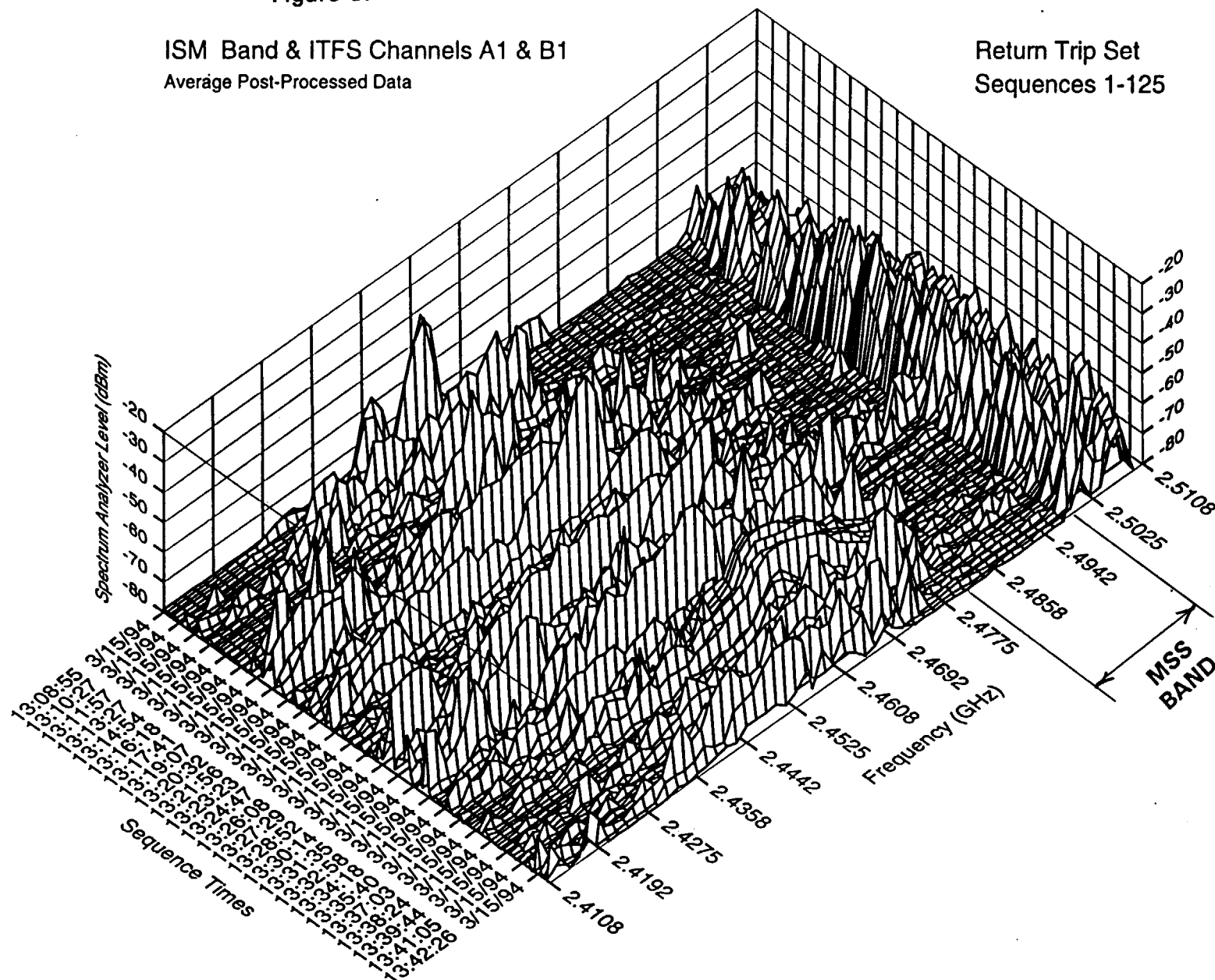F0315B.DG Avg    1

**Figure 6.**

ISM Band & ITFS Channels A1 & B1
Average Post-Processed Data

Return Trip Set
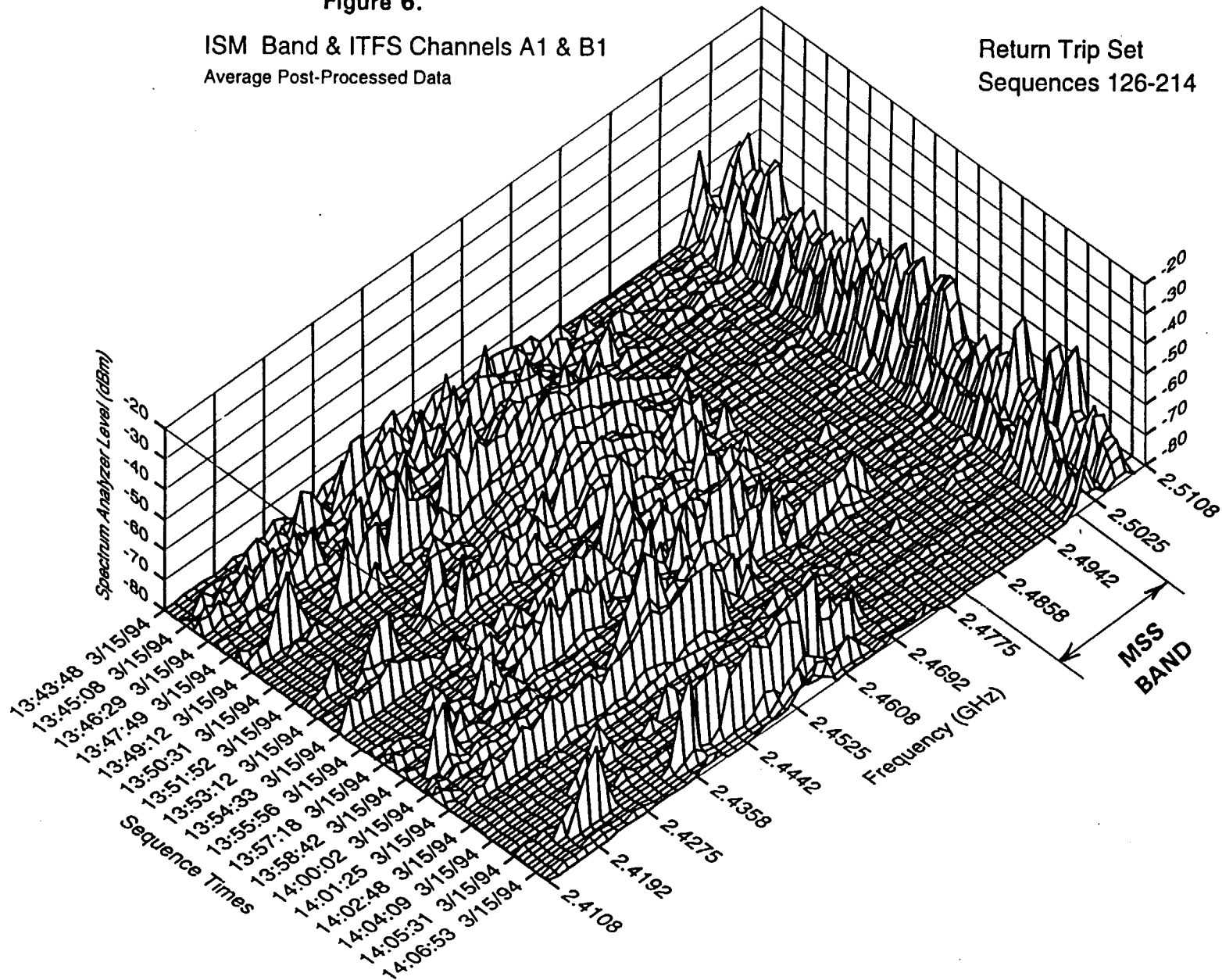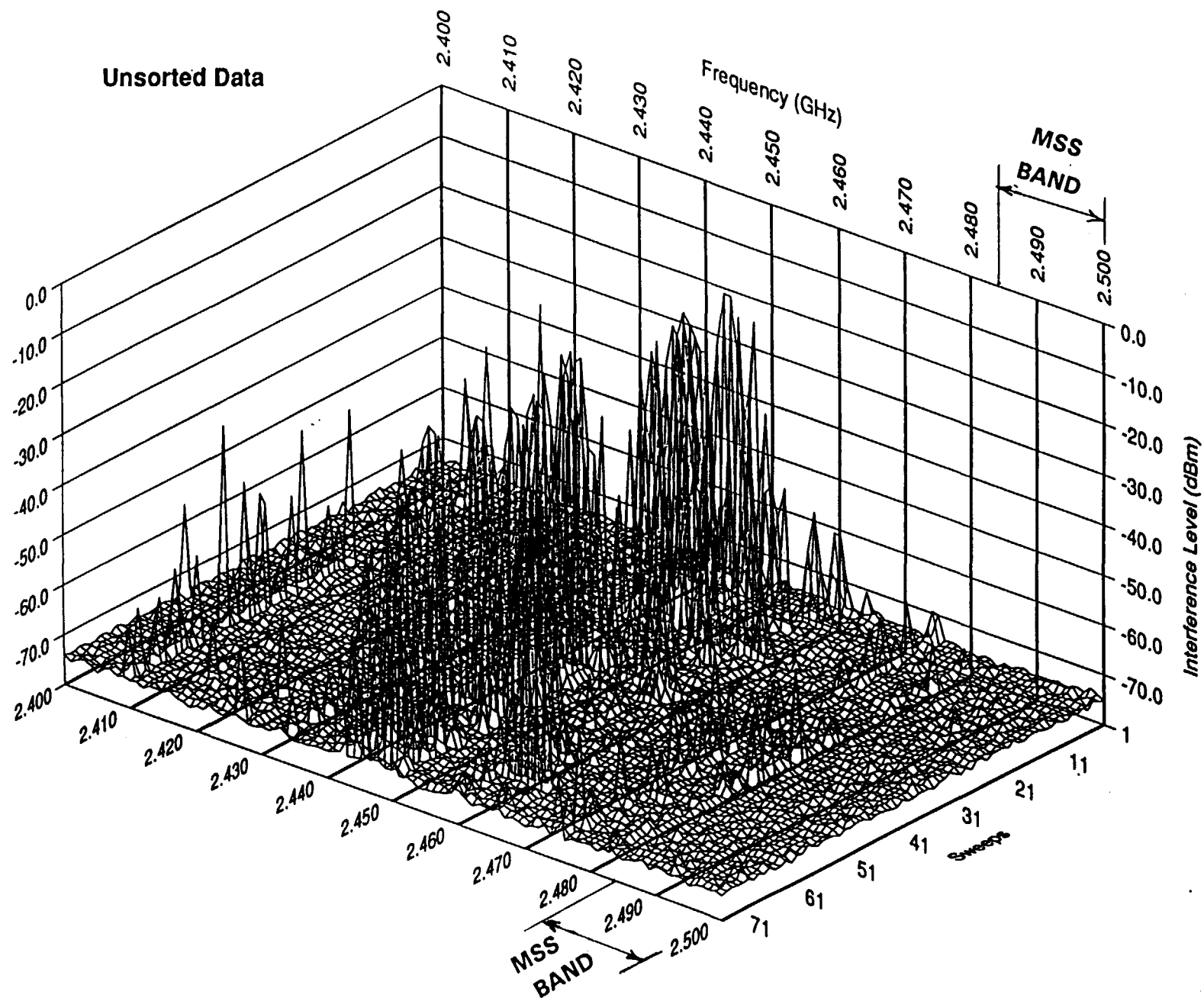Sequences 126-214



F0315B.DG Avg    2

Figure 7.

Microwave Oven Loral Building 21, September 28, 1993

**6**

# ATTACHMENT 6

CEPT PROJECT TEAM SE 18

FINAL REPORT

## FREQUENCY SHARING IMPLICATIONS OF FEEDER-LINKS FOR NON-GSO MSS NETWORKS IN FSS BANDS

1 FEBRUARY 1994

(Sections 1.8, 2, and 3 only)

# INDEX

## 1.8 Practicality of Reverse Band Working for the Non-GSO MSS Feeder Links, and its Effectiveness as a Solution to the Sharing Problem.

### 1. INTRODUCTION

In June 1991 ITU-R Working Party 4A adopted a new Report entitled "Methods for Control of Interference to FSS GSO Systems from Non-GSO Systems", and this Report was updated in September 1993. Among other things the updated Report lists areas for further work, and item e) of the list reads "Investigation of reverse band working as a possible way of avoiding 'in-line' outages".

The present paper has been prepared to summarise the outcome of such an investigation, focussing on potential interference between the feeder-links of Mobile Satellite Service (MSS) networks using Low Earth Orbits (LEOs) and other FSS networks using the geostationary orbit (GSO). The study so far has concentrated on this scenario because it seems likely to the authors that the feeder-links in LEO/MSS systems will be among the earliest instances of the use of LEOs in the FSS bands. (The up-links of BSS-Sound networks may also make use of non-geostationary orbits, but the indications are that these will take the form of high-apogee elliptical orbits (HEOs) rather than LEOs, and the work leading to Doc. 4A/Temp/24 (Rev 3) showed that instances of severe interference to and from GSO networks are unlikely to arise in that case ).

### 2. FSS FREQUENCY BANDS

As indicated in Table 1 below most FSS frequency allocations in the ITU Radio Regulations are unidirectional - ie they are either Earth-to space or space-to Earth allocations. In the few bands where reverse band (ie bi-directional) working is permitted the Earth-to-space direction is restricted to feeder-links of the Broadcasting Satellite Service (BSS), (with the single exception of the bi-directional allocation of the band 12.5-12.75 GHz in Region 1). Accordingly, in the present study it has been assumed that the LEO/MSS feeder-links would operate in reverse band mode - ie that they would use an FSS down-path band for their up-path transmissions and an FSS up-path band for their down-path transmissions. To

permit this to happen a future World Radiocommunication Conference (WRC) would have to approve appropriate amendments to RR Article 8, and it would seem sensible to restrict the reverse band working to the feeder-links of LEO/MSS networks.

TABLE 1    CURRENT FSS FREQUENCY ALLOCATIONS IN C, Ku AND Ka-BANDS*

| | Space-to-Earth | Earth-to-space |
|---|---|---|
| 4 GHz bands | 3.4-4.2 GHz | 5.9-6.7 GHz |
| 11/12/14 GHz Bands (Ignoring FSS Allotment Plan bands | 10.95-11.2 GHz and 11.45-11.7 GHz | Region 1 (10.95-11.2 GHz) (11.45-11.7) (Limited to BSS feeder-links) |
| | Region 1 12.5-12.75 GHz | Region 1 12.5-12.75 GHz |
| | Region 3 12.5-12.75 | Region 2 12.7-12.75 GHz |
| | | 13.75-14.0 GHz (with limitations on EIRP and dish size) |
| | | 14.0-14.5 GHz |
| 20/30 GHz bands | | 17.3-17.7 GHz (limited to BSS feeder-links) |
| | 17.7-18.1 GHz | 17.7-18.1 GHz (Limited to BSS feeder-links) |
| | 18.1-18.6 GHz | 18.1-18.4 GHz (limited to BSS feeder-links) |
| | 18.6-18.8 GHz (also allocated to passive EESS sensors) | |
| | 18.8-20.2 GHz (20.1-20.2 GHz also allocated to MSS) | |
| | | 27.5-31.0 GHz (29.9-30 GHz also allocated to MSS) |

* Note that these allocations apply to all Regions except where otherwise stated.

The selection of the most suitable up-path band and a
corresponding down-path band for reverse band operation of
LEO/MSS feeder-links is outside the scope of this paper, but
it would appear sensible to restrict the bi-directional usage
to two bands, each no wider than needed to accommodate the
envisaged feeder-link traffic.  In order to assist the choice
of such bands by a WRC this study has embraced carriers having
parameters suitable for C, Ku and Ka-band FSS allocations.
Thus we have :-

Normal GSO/FSS              Down-path  - 4, 11/12, and 20 GHz
                           Up-path    - 6, 14, and 30 GHz

LEO/MSS feeder-links       Up-path    - 4, 11/12 and 20 GHz
                           Down-path  - 6, 14 and 20 GHz


## 3.    INTERFERENCE MODES

Four modes of potential interference are thereby created:

    (i)    LEO/MSS feeder-link transmitting earth stations can
           interfere with GSO/FSS earth station reception.

    (ii)   GSO/FSS transmitting satellites can interfere with
           LEO/MSS feeder-link satellite reception.

    (iii)  LEO/MSS feeder-link transmitting satellites can
           interfere with GSO/FSS satellite reception.

    (iv)   GSO/FSS transmitting earth stations can interfere
           with LEO/MSS feeder-link earth station reception.

Figure 1 illustrates the worst cases for modes (i) and (iv),
and Figures 2A and 2B depict the worst cases for modes (ii)
and (iii).  Comparing Figure 1 with Figure 2, and bearing in
mind that the angular velocity of the LEO satellite will be an
order of magnitude higher than that of the GSO satellite, and
also that the earth stations will have narrow beams, it is
evident that the probability of a user suffering satellite-to-
satellite interference at the same time as earth station-to
earth station interference is very low.  Therefore it is
reasonable to allow the interference from each mode
independently to equal the single-entry criterion for the
carrier concerned.

## 3.1  Earth Station-to-Earth Station Interference

The worst cases for modes (i) and (iv) will occur when the
transmitting earth station is on a 180° bearing with respect
to the receiving earth station, and both are operating at 10°
elevation.  (It is assumed that neither earth station
transmits at elevation angles lower than 10°).  In all other
cases the joint antenna discrimination will be higher, so the
interference will be lower.

It should be noted that, since the LEO/MSS feeder-link earth
station is tracking a fast-moving satellite, this worst case
situation will occur only for small percentages of time - of
similar order to the 'in-line' outages in the non-reverse band
working case. And the level of interference will be far lower
than in-line' interference. Furthermore, the great majority
of GSO network earth-stations will operate at higher elevation
angles all of the time, and all of the LEO/MSS feeder-link
earth stations will operate at higher elevation angles for the
great majority of the time.

Figure 3 below illustrates the worst case (instantaneous)
situation. 'l' represents the interfering earth station and
'g' represents the victim earth station. 'H' caters for cases
where the interfering station has a relatively long line-of-
sight to the horizon.

Figure 3
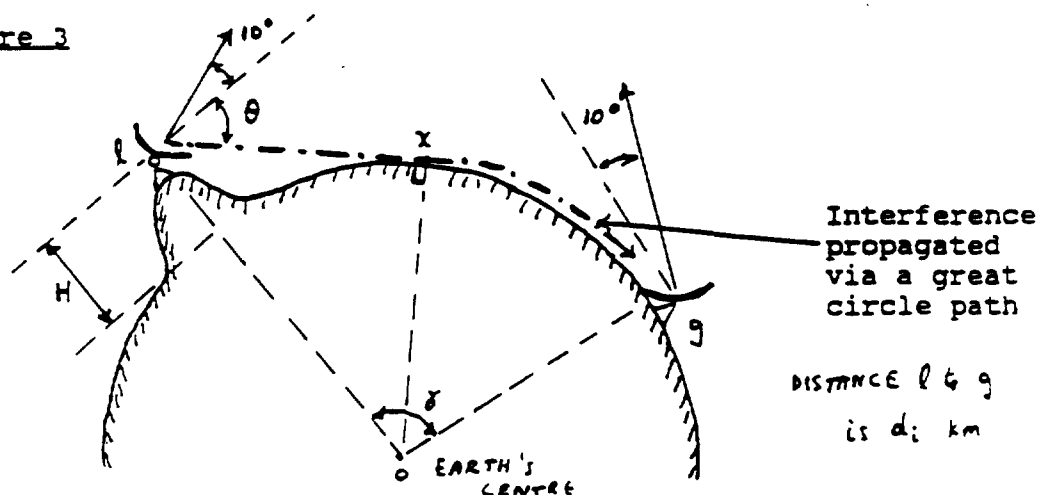


For coordination between earth stations the method described
in Annex 1 of ITU-R (CCIR) Recommendation 847 (1992) can be
used to determine short-term propagation loss. That document
details two propagation modes - great circle mechanisms (Mode
1) and scattering from hydrometeors (Mode 2). Since the
feeder-link earth station tracks relatively fast-moving
satellites which may appear anywhere in the visible sky, the
worst case depicted in the diagram will occur only
occasionally, and then only for short periods. It is
therefore arguable that the use of a short-term propagation
model is inappropriate for the present calculations, and that
a model for a continuous mode should be employed - eg free-
space loss within line-of-sight and diffraction thereafter.

However, in order to make some allowance for those relatively
rare circumstances when the worst case interference occurs at
the same time as a short-term propagation event (eg ducting),
it was decided to employ the method in Mode (1) (but not Mode
(2)) of Rec. 847, for a percentage of time (p) of 0.01 (ie the
great circle path loss which would be exceeded for all but
0.01% of time).

In order to apply this method it necessary to know the angle $\theta$ shown in the diagram, and hence the height 'H' above the mean Earth radius (6376 km). A figure of H = 1 km was selected as being reasonably conservative, which corresponds to $\theta = 1^\circ$ and a maximum line-of-sight (lx in the diagram) of 113 km.

For earth station-to-earth station transmission the 'wanted' carrier power (C) in the antenna feed of the receiving earth station is given by :-

$$C \text{ (dB)} = E_{sw} - 10\text{Log}[4.\pi.(d_w)^2] + G_{rew} + 10\text{Log}[(\lambda)^2/(4.\pi)]$$

and the interference power at the same point is given by:-

$$I \text{ (dB)} = E_{ei} - G_{tei} + [29 - 25\text{Log}(10^\circ)] - L_b(p)$$
$$+ [29 - 25\text{Log}(10^\circ)]$$

Where E denotes an EIRP, G denotes an antenna gain, $\lambda$ is the wavelength, and d denotes a transmission path length.

$L_b(p)$ is the path loss between the two antennas exceeded for all but p% of the time, in dB and using the nomenclature of Rec. 847, section 3.2. For the present calculations p = 0.01%.

Also suffix e indicates an earth station value,
     suffix s indicates a satellite value,
     suffix w relates to a 'wanted' signal,
     suffix i relates to an interfering signal,
     suffix r indicates a receive value and
     suffix t indicates a transmit value.

Hence, $C/I = E_{sw} - 10\text{Log}[4.\pi.(d_w)^2] + G_{rew} + 10\text{Log}(\lambda^2/4.\pi)$
$- E_{ei} + G_{tei} - 29 + 25\text{Log}(10^\circ) + L_b(p) - 29 + 25\text{Log}(10^\circ)$

$\therefore C/I = E_{sw} - 20\text{Log}(d_w) + G_{rew} - 20\text{Log}(f) - E_{ei} + G_{tei}$
$$+ L_b(p) - 40.44 \quad \text{dB} \quad \dots\dots\dots\dots(i)$$

The following evaluation of $L_b(p)$ is based on section 3.2 of Annex 1 of ITU-R (CCIR) Rec.847, commencing at equation (7); the equation numbers in that Annex are retained here.

$L_1 = L_b(p) - A_1$ ,
        where $A_1 = 120 + 20\text{Log}(f) + \text{Log}(p) + 5p^{0.5} + A_h$

From the diagram above, if H = 1 km, $\theta = -1^\circ$, so from equation 9c (in Rec. 847) $A_h = -4$.

Thus for p = 0.01% $L_1 = L_b(0.01) - 20\text{Log}(f) - 114.1 \dots (7,8)$

Section 3.1 of Rec. 847 divides the World into four basic radio-climatic zones. On the assumption that most feeder-

stations for land mobile and PCN satellite systems will be situated inland, only zone A2 ("all land, other than coastal land and shore") is considered here, for the sake of simplicity.

Thus equation (10) (in Rec. 847) becomes $L_1 = \beta(0.01).d_i$ dB

..... (10)

where $d_i$ in the present analysis is the whole length of the interfering path (not only of the $i^{th}$ segment as in Rec. 847).

From equation (11) (in Rec. 847)
$\beta(0.1) = 0.01 + \beta_{dz}(0.01) + \beta_o + \beta_{vz}$ dB/km ............. (11)

From equation (12) and Table 3 (in Rec. 847)
$\beta_{dz}(0.01)$ = 0.171056 dB/km  for 4 GHz
          = 0.193023 dB/km  for 11 GHz, and ............. (12)
          = 0.206005 dB/km  for 20 GHz.

From equation (13a) (in Rec. 847)
$\beta_o$ = 0.00615 dB/km  for 4 GHz
    = 0.00722 dB/km  for 11 GHz, and  ................... (13a)
    = 0.0137  dB/km  for 20 GHz.

From equation (14)
$\beta_{vz}$ = 0.000921145 dB/km  for 4 GHz
     = 0.008446526 dB/km  for 11 GHz, and  ............... (14)
     = 0.100832347 dB/km  for 20 GHz.

Substituting the figures from (12), (13a) and (14) into (11) gives
        $\beta(0.01)$ = 0.188127  dB/km  for 4 GHz
              = 0.208690  dB/km  for 11 GHz, and .... (11)
              = 0.320537  dB/km  for 20 GHz.

Re-arranging (7,8) gives $L_b(0.01) = L_1 + 20Log(f) + 114.1$

and, substituting in (i) above we get

$C/I = E_{sw} - 20Log(d_w) + G_{rew} - E_{ei} + G_{tei} + L_1 + 73.66$  dB.

Hence $L_1 = \beta(0.01).d_i = C/I - E_{sw} + 20Log(d_w) - G_{rew} + E_{ei}$

$- G_{tei} - 73.66$  dB ....... (ii)

$\beta(0.01)$ can then be substituted in (ii), and C/I set to the appropriate protection ratio, and $d_i$ thus calculated for each combination of 'wanted' and 'interfering' carriers.

## 3.2  Satellite-to-Satellite Interference

Figures 2A and 2B illustrate the worst case situation for global and spot beam systems respectively.  In the global beam situation, although some discrimination against interference might be available from the satellite antenna patterns, it is prudent to assume none since the situation is marginal.  In the spot beam case there will be no satellite antenna

discrimination when the satellites are (instantaneously) in the relative positions shown in Figure 2B.

Again, the relatively rapid motion of the LEO satellite ensures that the situation illustrated will occur only for short periods aggregating to a small proportion of the time. At all other times discrimination will be provided either by the LEO satellite antenna alone, or by both LEO and GSO satellite antennas, or by Earth blockage.

If the height (h) of the LEO is taken as 765 km (as for the IRIDIUM system), then from Figure 2  GL = 44892.8 km.

Thus, using the same nomenclature as in section 3.1 above, but relating C and I to the satellite receive antenna feed :-

$$C = E_{ew} - 10Log[4.\pi.(d_w)^2] + G_{rsw} + 10Log[(\lambda)^2/(4.\pi)]$$

$$\text{and } I = E_{si} - 10Log[4.\pi.(GL)^2] + G_{rsw} + 10Log[(\lambda)^2/(4.\pi)]$$

$$\therefore C/I = E_{ew} - E_{si} - 20Log(d_w) + 153.0 \quad dB \dots\dots\dots\dots \text{(iii)}$$

Note that at $10°$ elevation (ie worst case)  $d_w$ = 40585800m for the GSO, and 2293600m for a LEO of 765km height.

## 4.    CARRIER PARAMETERS

It is convenient to use the GSO/FSS and LEO/MSS feeder-link carrier parameters given in Table 1 of Annex 1 to ITU-R WP4A Report (Doc.4A/Temp/24 - Rev 3), and the protection ratios given in Table 2 of that Annex (ie pages 166, 167 and 168 of  Doc. 4A/Temp/24 - Rev 3)*, and the protection ratios given in wanted/interfering carriers (2x12 for C-band, 2x4 for Ku-band and 2x2 for Ka-band), ignoring HEO/BSS feeder-link carriers 15, 16 and 17.  For convenience the GSO/FSS parameters needed for the present study are repeated in Table 2 overleaf :-

* Except that the parameters in column 14, which were derived from early Iridium system feeder link parameters, have been updated to take account of the fact that the Iridium design has been changed to include dynamic power control on the up and down path feeder links.  The parameters in columns 11 and 13 were also derived by scaling the original Iridium parameters for the lower frequencies.  These have not been changed however, because it is considered that Ku-band and C-band feeder-links would operate with carrier power margins rather than power-control.

TABLE 2    GSO/FSS CARRIER PARAMETERS

| Service | 1 INTE-LSAT VI MAX | 2 INTE-LSAT VI MAX | 3 INTE-LSAT VI MAX | 4 INTE-LSAT Future MAX | 5 INTE-LSAT VI MAX | 6 INTE-LSAT VI MAX | 7 INTE-LSAT VI MAX | 8 INTE-LSAT Future MAX |
|---|---|---|---|---|---|---|---|---|
| Orbit type | GSO | GSO | GSO | GSO | GSO | GSO | GSO | GSO |
| Frequency Band | C | C | Ku | Ka | C | C | Ku | Ka |
| Beam type | Globl | Hemi | Spot | Spot | Globl | Hemi | Spot | Spot |
| Carrier B/W (MHz) | 30 | 30 | 27 | 30 | .0512 | .0512 | .0512 | 0.0512 |
| Carrier type | FM/TV | FM/TV | FM/TV | FM/TV | 64kB/S IDR | 64kB/S IDR | 64kB/S IDR | 64kBit/S IDR |
| $E_s$ (dBW) | 30.5 | 35.0 | 50.0 | 61.5 | 0.5 | 0.9 | 7.7 | 19.2 |
| $E_e$ (dBW) | 85.4 | 87.8 | 86.3 | 86.3 | 48.3 | 46.1 | 40.9 | 40.9 |
| $G_{re}$ (dBi) | 54.0 | 54.0 | 60.2 | 60.2 | 47.7 | 47.7 | 53.5 | 53.5 |
| $G_{te}$ (dBi) | 57.8 | 57.8 | 62.3 | 62.3 | 51.6 | 51.6 | 55.5 | 55.5 |

For the LEO/MSS feeder-link carrier parameters adjustments must be made for the fact that the up-path and down-path frequencies will be reversed.  This can be done in the following manner :-

As on page 164 of Doc. 4A/181, for a satellite-to-Earth or Earth-to-satellite transmission path

$$C_r = C_t + G_t + G_r - 20Log(f) - 20Log(d) - M - 32.44$$

Where $C_r$ = received carrier power (dBW),
$C_t$ = transmitted carrier power (dBW),
$G_t$ = antenna transmit gain (dBi),
$G_r$ = antenna receive gain (dBi),
$f$ = frequency (GHz),
$M$ = rain margin (dB), and
$d$ = distance between transmit and receive antennas (metres).

In the exchange of up and down-path frequencies $C_r$ can be assumed to remain the same since the performance requirements will be the same, and d will also remain constant. Additionally it can be initially assumed that the same satellite antenna gains would be needed, since the required coverages would not change.

Hence we may write, for the up-paths

$$\Delta (C_t + G_t) = \Delta[20\text{Log}(f) + M]$$

9

and for the down-paths

$$\Delta (C_t + G_r) = \Delta[20\text{Log}(f) + M]$$

Further, it is reasonable to assume initially that the earth station antennas would be of the same size, so their gains would simply reflect the frequency change [ie $\Delta 20\text{Log}(f)$].

So, for the up-paths $\Delta G_t = \Delta[20\text{Log}(f)]$

and for the down-paths $\Delta G_r = \Delta[20\text{Log}(f)$.

Hence for up and down paths $\Delta C_t = M$ and $\Delta E = \Delta G_t + \Delta C_t$ .

In Table 3 below the 0.1% of worst month rain margins for CCIR rain climate 'J' are indicated :-

TABLE 3    RAIN MARGINS

| f (GHz) | M (dB) | ∴ΔM (dB) | also Δ[20Log(f)] |
|---|---|---|---|
| 4.0 | 0.13 ) | | |
| | ) | +/- 0.54 | +/- 3.52 |
| 6.0 | 0.67 ) | | |
| 11.0 | 4.28 ) | | |
| | ) | +/- 2.80 | +/- 2.09 |
| 14.0 | 7.08 ) | | |
| 20.0 | 13.67) | | |
| | ) | +/- 12.13* | +/- 3.52 |
| 30.0 | 25.80) | | |

* In this case it is not reasonable to assume that satellite or earth station transmitter power will be increased by 12 dB. So for Ka-band it is assumed that for reverse band working the feeder-link earth station antennas would have double the diameter implied in column 14 on page 167 of Doc.4A/181 (ie from 3m to 6m), and that the satellite beams would be halved in width (ie more beams would be employed). Thus for Ka-band, in both up and down-paths,

$$\Delta G_t = 6\text{dB} +/- \Delta[20\text{Log}(f)] \quad \text{and} \Delta G_r = 6\text{dB} +/- \Delta[20\text{Log}(f)],$$

and hence $\Delta C_t$ remains the same on both paths, while $\Delta E = \Delta G_t$ .

When adjusted for reverse band working in the foregoing manner, the LEO/MSS feeder-link parameters in Table 1(b) on page 167 of Doc. 4A/181 become are as shown in Table 4 below.

TABLE 4    LEO/MSS FEEDER-LINK CARRIER PARAMETERS

| Service | 9 LEO MSS feeder-link | 10 LEO MSS feeder-link | 11 LEO MSS feeder-link | 12 LEO MSS feeder-link | 13 LEO MSS feeder-link | 14 LEO MSS feeder-link |
|---|---|---|---|---|---|---|
| Orbit type | Circulr 765 km | Circulr 765 km | Circulr 765 km | Circulr 765 km | Circulr 765 km | Circular 780 km |
| Frequency band | C | C | C | Ku | Ku | Ka |
| Beam type | Spot | Spot | Spot | Spot | Spot | Spot |
| Carrier B/W (MHz) | 0.922 | 0.00072 | 6.25 | 0.126 | 6.25 | 3.09 |
| Carrier type | QPSK 1536kBS | BPSK 0.6kB/S | 6.25 MBit/S | PCN TD-MA/FDMA | 6.25 MBit/S | QPSK 2/3 FEC |
| $E_s$ (dBW) | -10.3 (-14.6) | -44.0 (-48.1) | 7.7 (3.6) | 2.4 (-2.5) | 15.5 (10.4) | 23.0 (13.5) |
| Ee (dBW) | 47.9 (52.0) | 24.7 (28.8) | 34.5 (38.6) | 49.9 (54.8) | 47.2 (52.1) | 45.7 (43.2) |
| $G_{re}$ (dBi) | 52.7 (49.2) | 52.7 (49.2) | 43.5 (40.0) | 51.3 (49.2) | 50.9 (48.8) | 62.5 (53.0) |
| $G_{te}$ (dBi) | 50.5 (54.0) | 50.5 (54.0) | 40.0 (43.5) | 49.2 (51.3) | 48.8 (50.9) | 57.8 (55.3) |

(Note  bracketed figures are those prior to the adjustments for reverse band working).

Each protection ratio is influenced only by

   a)   the permissible level of interference for the wanted carrier, which is simply a fraction of the total noise at the demodulator input, which in turn is determined by the performance requirement, which itself will remain unchanged;

   b)   the ratio of the interfering and wanted carrier bandwidths,

   c)   and, in some cases the spectral power distribution of one or other, or both of the carriers.

Thus the protection ratios given on page 168 of Doc.4A/181 will not be affected by the change to reverse band working*, and for the convenience of the reader these are reproduced, in dB, in Table 5 below :-

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*Except those involving carrier 14, where the bandwidth has changed in the updating.

TABLE 5(a)    PROTECTION RATIOS FOR GSO/MSS CARRIERS
INTERFERING WITH LEO/MSS FEEDER-LINK CARRIERS

| Wanted carrier LEO/MSS feeder link | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|
| **Interfering carrier GSO/FSS** | | | | | | |
| 1 | 16.96 | -16.14 | 19.12 | | | |
| 2 | 16.96 | -16.14 | 19.12 | | | |
| 3 | | | | 16.11 | 19.12 | |
| 4 | | | | | | 22.12 |
| 5 | 32.3 | -0.22 | 39.0 | | | |
| 6 | 32.3 | -0.22 | 39.0 | | | |
| 7 | | | | 39.0 | 39.0 | |
| 8 | | | | | | 42.0 |

TABLE 5(b)    PROTECTION RATIOS FOR LEO/MSS FEEDER-LINK
CARRIERS INTERFERING WITH GSO/FSS CARRIERS

| Wanted carrier GSO/FSS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **Interfering carrier LEO/MSS feeder link** | | | | | | | | |
| 9 | 46.0 | 46.0 | | | 9.36 | 9.36 | | |
| 10 | 77.0 | 77.0 | | | 40.0 | 40.0 | | |
| 11 | 38.0 | 38.0 | | | 1.05 | 1.05 | | |
| 12 | | | 54.0 | | | | 18.01 | |
| 13 | | | 37.0 | | | | 1.05 | |
| 14 | | | | 35.0 | | | | -1.95 |

## 5. RESULTS

### 5.1 Results for Earth Station-to-Earth Station Interference

By substituting the parameters and protection ratios in Tables 2, 4 and 5 into equation (i) the following values of $d_i$ (in km) for the worst case earth station-to-earth station situation (see Figure 1) were calculated, and are presented in Table 6.

For a number of carrier combinations the value of $d_i$ thus calculated was less than the assumed horizon distance (113km), and in some of these cases it was less than the value calculated assuming free-space path loss. It was therefore decided to substitute free-space loss [ie $10Log(4\pi.d_i^2)$ dB] in the calculations whenever the method of Rec. 847 (Mode 1) yielded a value less than the horizon distance for 4/3 x the Earth's radius (ie about 130 km for H = 1 km). In those cases where the free-space assumption yielded $d_i$ > 130 km but the Rec. 847 (Mode 1) method yielded $d_i$ < 130 km, then $d_i$ was calculated assuming free-space loss up to 130 km plus 2 dB/km for the remaining distance.

TABLE 6    WORST CASE DISTANCES ON THE EARTH'S SURFACE BEYOND
            WHICH EARTH STATION-TO-EARTH STATION INTERFERENCE
            WOULD BE ACCEPTABLE (in km).

Table 6A    Interference from GSO/FSS to LEO/MSS feeder-link.

| Wanted carrier LEO/MSS feeder link | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|
| Interfering carrier GSO/FSS | | | | | | |
| 1 | 296.1 | 299.3 | 260.8 | | | |
| 2 | 308.8 | 312.0 | 273.5 | | | |
| 3 | | | | 191.5 | 145.1 | |
| 4 | | | | | | 62.5 |
| 5 | 213.4 | 219.6 | 202.2 | | | |
| 6 | 201.7 | 207.9 | 190.5 | | | |
| 7 | | | | 131.8 | 45.8 | |
| 8 | | | | | | 7.2 |

## 6.   CONCLUSIONS

As a typical example the results in section 5 were derived for a LEO height of 765 km.  A separate study by the authors indicates that similar results would be obtained for MSS feeder-links using other LEO heights between 500 and 1500 km.

Addressing the satellite-to-satellite interference case first, the results in Table 7B contains no negative values, which indicates that even in the most adverse circumstances none of the carrier combinations lead to unacceptable interference levels.  Indeed, most of the margins are substantial;  this is not surprising since the 'wanted' carrier power derives from an earth station, while the interfering carrier power derives from a satellite and has a greater distance to travel.  The same is true from Table 7A except for one Ka-band case.

Turning to the earth station-to-earth station interference results in Tables 6A and 6B, they are believed to err on the side of caution.  For the value of H assumed the interfering earth station-to-horizon distance is about 113 km.  For distances greater than 130 km a great circle propagation mode applicable for 0.01% of time has been employed where appropriate, and an attenuation rate of 2 dB/km otherwise.

Since the distances in Table 6 are those beyond which interference would be within acceptable limits for the carrier combinations concerned, they may be seen as distances within which coordination might be required.  The distances in the Table are not in themselves unreasonable in the coordination context, but in practice very few cases of unacceptable interference would occur even if the two earth stations were located closer to each other.  First, the great majority of FSS/GSO network earth stations operate at elevation angles greater than $10^\circ$.  Second, it is clear from Figure 1 that the great majority of LEO/MSS feeder-link earth stations are likely to be located such that their azimuth pointing directions cannot have a $180^\circ$ alignment with the azimuth pointing direction of a GSO/FSS earth station less than 200 km away.  Third, for the great majority of the time the elevation angle of each LEO/MSS feeder-link earth station antenna will be greater than $10^\circ$.

A simple diagram may help to illustrate these points.  Equation (i) in section 3.1 implicitly contains a term $50\text{Log}(10^\circ)$ - ie 50dB, reflecting the joint discrimination of the two earth station antennas at minimum operational elevation angles and instantaneously on reciprocal azimuth bearings.  The diagram below depicts the general case where the two elevation angles are $\phi_1$ and $\phi_2$ and the azimuth angles are $\alpha_1$ and $(180 - \alpha_2)$ degrees.